CE-MR Angiography at 3.0 T Magnetic Field in the Study of Spinal Dural Arteriovenous Fistula
Preliminary Results

L. ALBINI RICCIOLI, A. F. MARLIANI, P. GHEDIN, R. AGATI, M. LEONARDI
Servizio di Neuroradiologia, Ospedale Bellaria, Bologna, Italy

Key words: 3.0 T MRI, CE-MRA, vascular malformations, arteriovenous fistula, Adamkiewicz's artery, TRICKS

Summary

We report technical data and results in eight patients studied with spinal contrast-enhanced MR angiography (CE-MRA). We used a 3.0 Tesla device, dedicated phased array coil and time resolved imaging of contrast kinetics (TRICKS) sequences to visualize the feeder vessels in patients with vascular malformations. TRICKS is a method of 3D CE-MRA providing temporal information. Thanks to its high temporal and spatial resolution and high signal/noise ratio the TRICKS optimized sequence at 3.0 T yielded very encouraging results in disclosing the origin of arteriovenous malformations

Introduction

Spinal vascular malformations are uncommon and account for around 16% of all expanding spinal lesions [1].

Dural arteriovenous fistulae are the commonest malformations encountered in adults after the fourth and fifth decade of life and there is a male predominance (85%) [2]. These lesions are often difficult to identify as the clinical features and non invasive radiological findings may mimic those of a tumour or infection [3,4]. It is important to clarify the lesion on MR images because surgical and endovascular treatments are relatively straightforward and are associated with low morbidity and mortality rates [5]. Intra-arterial digital subtraction angiography is the gold standard in the diagnosis of vascular malformations as its high spatial and temporal resolution will offer details of the lesion's architecture. However, the examination is difficult and not without risk, especially in elderly patients who often present atheromatous disease. The invasiveness of the procedure, nephrotoxicity of iodinated contrast media and radiation exposure led to the development of non invasive imaging techniques [6-10] including Contrast-Enhanced MR Angiography (CE-MRA) which has yielded very encouraging results.

Material and Methods

From March 2005 to November 2006 eight patients underwent spinal CE-MR angiography. The patients, seven men and one woman, with a mean age of 61.8 years (45-85), were studied by spinal MRA for suspect arteriovenous fistula. All patients had an MR scan without and with contrast administration before CE-MRA.

MR angiographic images were obtained using a 3 Tesla MR system (Signa EXCITE 3T GE Medical Systems, Milwaukee,WI, USA). A dedicated eight channel phased array coil (USAI 8chCTL coil) and TRICKS optimized sequence were used with the acquisition parameters reported in table 1. MR angiographic images were obtained in the coronal plane to identify the feeders of vascular malformations. Digital angiography (DSA) was performed in six subjects (11,12,13). DSA could not carried out in one patient due to severe calcified atheromatous plaque of the aorto-iliac complex, but MRA findings were confirmed at surgery. DSA was not performed in another patient because of her poor clinical condition and advanced age.

The majority of spinal dural AVFs are found from the mid-thoracic to the upper lumbar regions of the spinal canal. Less commonly, however, a spinal dural AVF can reside within the upper thoracic, lower lumbar, sacral, and intracranial regions. Spinal dural AVFs have also been reported in the cervical region. Therefore, complete evaluation of the spinal canal from cranium to sacrum may be required to find the spinal dural AVF in these patients. If the site of the fistula was not identified during this first examination the patient may returned to have the other regions evaluated on another occasion [9,10].

Contrast medium (0.3 mmol/kg gadopentate dimeglumine, Magnevist; Schering Berlin, Germany) was injected at 2 ml/s by means of an MR injector (Spectris Solaris SSMR 300, Medrad, Pittsburgh, Pa) through a 20-gauge angiographic catheter placed in an anterocubital vein. The maximum concentration of gadolinium should be present during acquisition of central k-space lines to optimize image contrast [14].

Table 1 **TRICKS: acquisition parameters (coronal sequence).**

Acq.Time	1:10
Temp. Res.	0:04
Phases	9
Matrix	384x192
TR	3.8
TE	1.5
FA	20
Bandwidth	100
NEX	0.5
FOV	35
THK	2 mm
Scan locks	46

A

Optimal timing requires estimation of the contrast material travel time using the test bolus method [15]. Our spinal MRA technique involves a preliminary bolus test at T12 level, injecting 2 ml of gadopentetate dimeglumine at 2 ml/s followed by saline flush of 10 ml. A precontrast mask image was acquired. The average imaging time was 20 minutes, and the average postprocessing time was ten to 20 minutes. All MR angiograms were processed at the MR imager console. Maximum intensity projection (MIP) data were calculated for each image set. Multiplanar reformatting was applied to display the feeders and venous drainage of AVF [5,16,17,18]. The AVF were visualized by cine-loop display of native images.

All images were independently examined and processed by two radiologists (AFM, LAR). MR angiographic studies were evaluated without knowledge of the results obtained at digital angiography.

Informed consent was obtained from all patients for spinal MRA and all examinations were completed without complications.

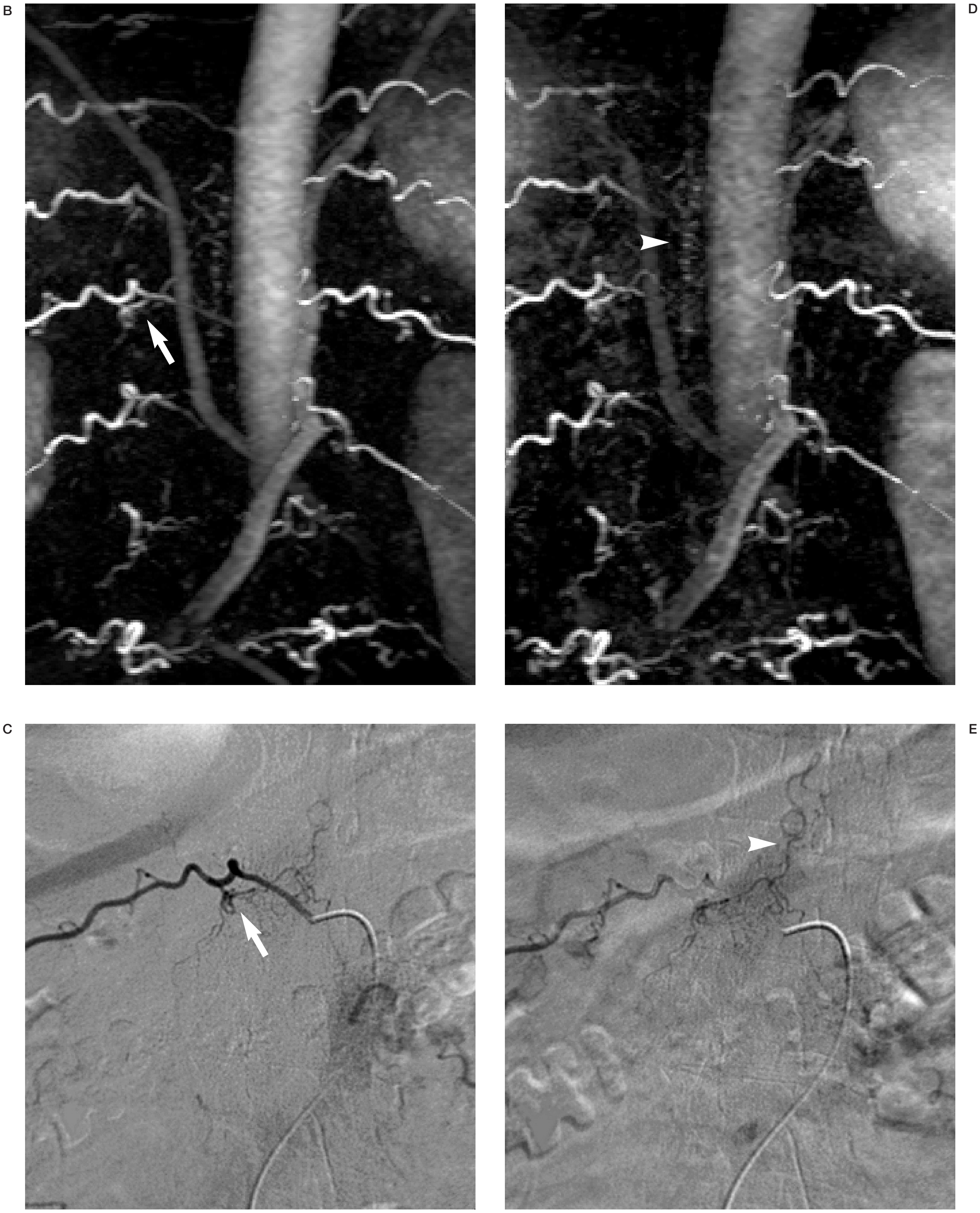

Figure 1 A) Sagittal T2 FAT SAT MR scan: signal hyperintensity in the conus medullaris which is enlarged (arrow) and surrounded by serpiginous vessels (arrowhead). B,C) MR angiography and digital angiography in the early phase: spinal dural arteriovenous fistula arising from the right T11 intercostal artery (arrow). D,E) MR angiography and digital angiography in a later phase: note the tortuous venous drainage (arrowhead).

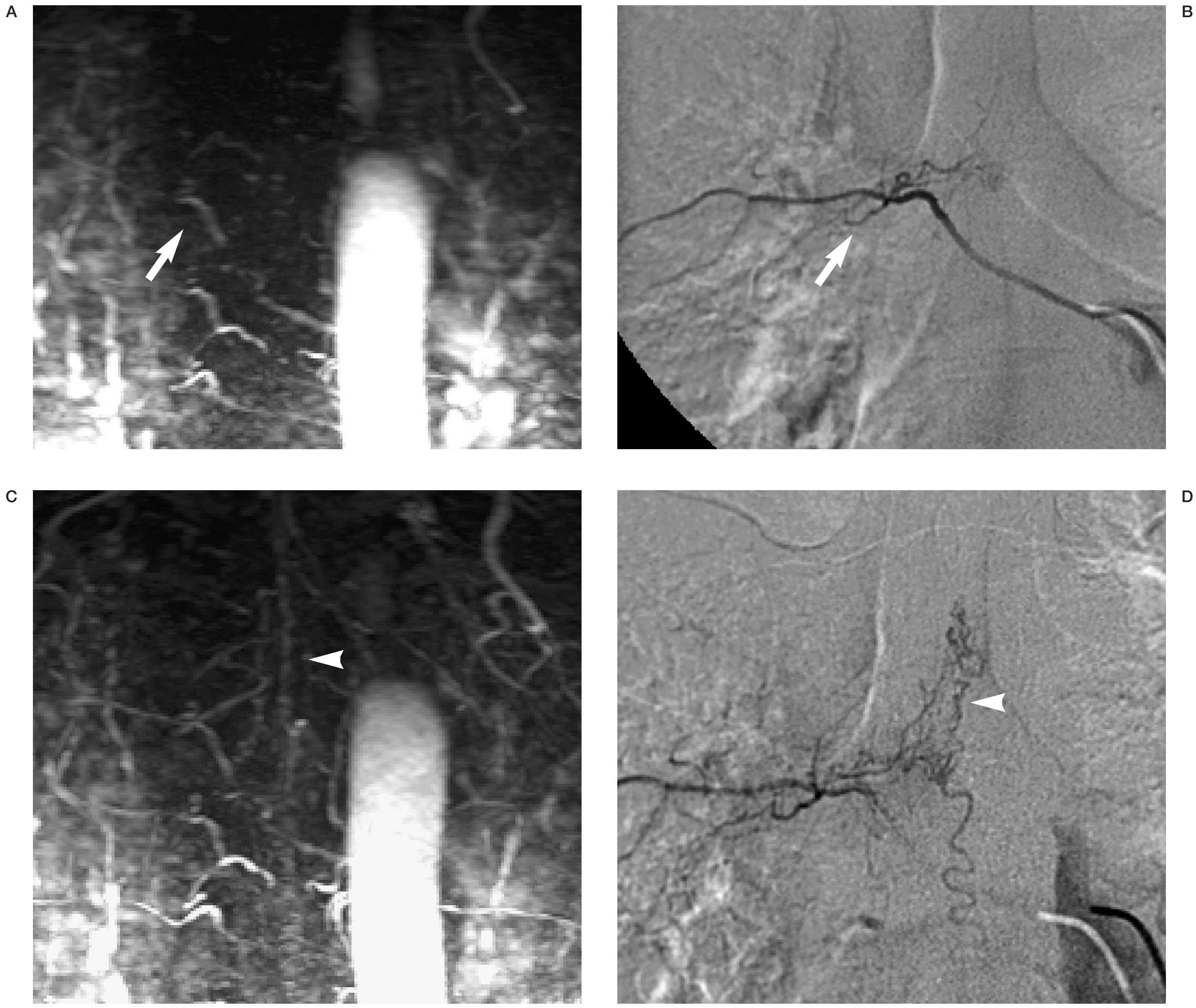

Figure 2 Dural arteriovenous fistula arising from the right T6 intercostal artery: A,B) MR angiography and digital angiography in the early phase (arrow). C,D) and later (arrowhead).

Table 2 **MR angiographic findings in 8 patients with spinal cord vascular malformations.**

CASE	AGE/SEX	FEEDERS	DIAGNOSIS	DSA	AGREEMENT
1	65/M	D11 R	AVF	Performed	Yes
2	67/M	D7 R	AVF	Not performed	At surgical
3	66/M	D6 R	AVF	Performed	Yes
4	62/M	D11 R	AVF	Performed	Yes
5	46/M	D10 R	AVF	Performed	Yes
6	45/M	D9 R	AVF	Performed	Yes
7	85/F	D8 L	AVF	Not performed	
8	59/M	D11 R	AVF	Performed	Not

Results

CE MRA displayed the feeders of vascular malformations in eight patients (Table 2) and showed a single feeder to AVF in all of them. CE MRA findings were confirmed by digital angiography in five patients and by surgery in another. (figures 1 and 2)

The two techniques yielded discordant findings in one patient in whom angiography indicated the origin of the dural fistula at a different level from the CE MRA study. A review of this case disclosed a technical error on acquisition of the MRA sequence due to incorrect activation of the coil. DSA was not performed in one elderly woman because of her poor clinical condition and advanced age. All our patients had dural fistulae with slowly progressive paraparesis with venous hypertension and low flow.

Discussion

Many authors have reported encouraging results studying the spinal vasculature by MR angiography using a 1.5 T system to characterize spinal vascular lesions and identify their arterial feeders and venous drainage [1,5,18].

With 3.0 T systems MR angiography offers significant advantages with respect to lower magnetic field devices. The higher signal-noise ratio improves imaging quality largely due to wider acquisition matrices without significant image granulosity. Spatial resolution can be increased, reducing the effects of partial volume and thereby disclosing structures difficult to visualize with 1.5 T MR systems (e.g. vessels measuring 0.2-0.3 mm). Temporal resolution can also be enhanced thanks to a drastic cut in examination times [19].

First introduced by the University of Wisconsin-Madison group, time resolved imaging of contrast kinetics (TRICKS) is a method of 3D contrast enhanced magnetic resonance angiography (MRA) providing temporal information [20-26]. TRICKS combines variable rate k-space sampling, temporal interpolation of k-space views, view sharing and zero filling in the slice-encoding dimension. The interest in the method lies in its ability to acquire a pure arterial weighted phase, while TRICKS allows ultraresolved 3D contrast enhanced MRA (CE-MRA) without venous contamination. For these reasons TRICKS has been used for evaluation of spinal CE MRA.

Due to the very small size of spinal vessels a bolus test is necessary to study the vertebral medullary vascularization. TRICKS uses a keyhole method that provides improved temporal resolution by acquiring low spatial frequency more often than high spatial frequency information. The keyhole technique has been generalized in the BRISK (block regional interpolation scheme for k-space) algorithm demonstrated by Doyle et Al. in 1995 [27].

The 3D TRICKS sequence with a Signa EXCITE 3T system is the first acquisition method combining the characteristics of TRICKS (variable rate k-space sampling, temporal interpolation of k-space views, view sharing, and zero filling) and elliptic centric view ordering [28]. Until now, only sequential or centric view ordering has been possible. The limitation of sequential or centric k-space filling is that both high and low spatial frequencies are acquired leading to non optimal capture of the arterial phase and to some unwanted venous enhancement.

The use of an elliptic centric encoding for the TRICKS method has proved to yield higher arterial and venous contrast [29]. As an all time resolved technique, TRICKS needs a compromise between temporal and spatial resolution. Precontrast masks are acquired at the beginning of the acquisition process to eliminate the background signal.

This technique presents some limitations like patient motion and amount of data. Patient motion during the temporal window results in misregistration of data. Motion during only one frame can corrupt several temporally resolved image volumes. The amount of data poses a major problem in data handling and reconstruction time. An off-line reconstruction is necessary but still not sufficient. The maximum number of images acquired in each study is limited to 1024.

Conclusions

Our preliminary experience indicates that spinal CE MRA using a clinical 3.0 T system equipped with TRICKS optimized sequence and standard coil with high spatial resolution, high temporal resolution and correct gadolinium injection can display the AVF feeding vessels.

The marked K-space segmentation used in the TRICKS sequence allowed the spatial resolution of acquisitions to be expanded up to voxel dimensions smaller than mm 3. These resolution levels are required to display the smallest arteries without major artifacts caused by flow and venous contamination [30].

CE MRA provides additional information with respect to traditional MRI without significantly increasing overall examination times and patient discomfort [1].

Although digital angiography remains essential in the study of vascular malformations, MRA following standard MR scans is a reliable non invasive technique which can be repeated to yield information useful for subsequent digital angiography and patient follow-up after endovascular or neurosurgical treatment.

References

1 Binkert CA, Kollias SS, Valavanis A: Spinal Cord Vascular Disease: Characterization with Fast Three-Dimensional Contrast-Enhanced MR Angiography. Am J Neuroradiol 20: 1785-1793, 1999.

2 Berenstein A, Lasjaunias P: Surgical Neuroradiology: Endovascular Treatment of Spine and Spinal Cord Lesions. Springer-Verlag, Berlin Heidelberg 1992: 1-24.

3 Symon L, Kuyama H, Kendall B: Dural Arteriovenous Malformations of the Spine: Clinical Features and Surgical Results in 55 Cases. J Neurosurg 60: 238-247, 1984.

4 Rosenblum DS, Myers SJ: Dural Spinal Cord Arteriovenous Malformation. Arch Phys Med Rehabil 72: 233-236, 1991.

5 Saraf-Lavi E, Bowen BC et Al: Detection of Spinal Dural Arteriovenous Fistulae with MR Imaging and Contrast-Enhanced MR Angiography: Sensitivity, Specificity and Prediction of Vertebral Level. Am J Neuroradiol 23: 858-867, 2002.

6 Hany TF, Carrol TJ et Al: Aorta and runoff vessels: single-injection MR angiography with automated table movement compared with multiinjection time-resolved MR angiography-initial results. Radiology 221: 266-272, 2001.

7 Katayama H, Yamaguchi K et Al: Adverse reactions to ionic and nonionic contrast media. A report from the Japanese Committee on the Safety of Contrast Media. Radiology 175: 621-628, 1990.

8 Waugh JR, Sacharias N: Arteriographic complications in the DSA era. Radiology 182: 243-246, 1992.

9 Berenstein A, Lasjaunias P, Ter Brugge KG: Surgical Neuroangiography. Springer-Verlag, Berlin Heidelberg 2004: 859-866.

10 Farb RI, Kirn JK et Al: Spinal dural arteriovenous fistula localization with a technique of first-pass gadolinium-enhanced MR angiography: initial experience. Radiology 222: 843-850, 2002.

11 Marliani AF, Pastore Trossello M: Diagnostic and therapeutic vertebral and spinal angiography. Rivista di Neuroradiologia 12: 6, 1999.

12 Thron AK: Vascular anatomy of the spinal cord: neuroradiological investigation and clinical syndromes. Springer-Verlag, New York, 1998: 1-113.

13 Thron AK, Mull M: Blood vessels of the spinal cord: anatomical and MR-imaging correlation. Rivista di Neuroradiologia 17: 277-281, 2004.

14 Carroll TJ, Swan JS et Al: Technical Reliability of Time-Resolved CE MRA for the Assessment of Peripheral Vascular Occlusive Disease. Proc Intl Soc Mag Reson Med Glasgow, Scotland, 2001.

15 Van Hoe L, De Jaegere T et Al: Breath-hold contrast-enhanced three-dimensional MR angiography of the abdomen: time-resolved imaging versus single-phase imaging. Radiology 214: 149-156, 2000.

16 Bowen BC, Fraser K et Al: Spinal dural arteriovenous fistulas: evaluation with MR angiography. Am J Neuroradiol 16: 2029-2043, 1995.

17 Bowen BC, DePrima S et Al : MR angiography of normal intradural vessels of the thoracolumbar spine. Am J Neuroradiol 17: 483-494, 1996.

18 Mascalchi M, Ferrito G et Al. Spinal vascular malformations: MR angiography after treatment. Radiology 219: 346-353, 2001.

19 Scarabino T, Nemore F et Al: Semeiological features of 3.0T MR imaging: what changes at high magnetic field. Rivista di Neuroradiologia 17: 755-764, 2004.

20 Korosec FR, Frayne R et Al: Time-resolved contrast-enhanced 3D MR angiography. Magn Reson Med 36: 345-351, 1996.

21 Carroll TJ, Korosec FR et Al: Carotid biforcation: evaluation of time-resolved three-dimensional contrast-enhanced MR angiography. Radiology 220: 525-532, 2001.

22 Carroll TJ, Korosec FR et Al: The effect of injection rate on time-resolved contrast-enhanced peripheral MRA. J Magn Reson Imaging 14: 401-410, 2001.

23 Turski PA, Korosec FR et Al: Contrast-Enhanced magnetic resonance angiography of the carotid bifurcation using the time-resolved imaging of contrast kinetics (TRICKS) technique. Topics in MRI 12: 175-181, 2001.

24 Carroll TJ, Korosec FR et Al: Method for rapidly determining and reconstructing the peak arterial frame from a time-resolved CE-MRA exam. Magn Reson Med 44: 817-820, 2000.

25 Mistretta CA, Grist TM et Al: 3D time-resolved contrast-enhanced MR DSA: advantages and tradeoffs. Magn Reson Med. 40: 571-581, 1998.

26 Mistretta CA et Al: X-ray digital subtraction angiography to magnetic resonance-digital subtraction angiography using three-dimensional TRICKS. Historical perspective and computer simulations: a review. Invest Radiol 33: 496-505, 1998.

27 Doyle M, Walsh EG et Al: Block regional interpolation scheme for k-space (BRISK): a rapid cardiac imaging technique. Magn Reson Med 33: 163-170, 1995.

28 Naganawa S, Koshikawa T et Al: Contrast-enhanced MR angiography of the carotid artery using 3D time-resolved imaging of contrast kinetics: comparison with real-time fluoroscopic triggered 3D-elliptical centric view ordering. Radiation Medicine 19: 185-192, 2001.

29 Zhou Y: FUSION for Incremental Field-of-View. Imaging Proc Intl Soc Mag Reson Med Glasgow, Scotland, 2001.

30 Albini Riccioli L, Marliani AF et Al: Magnetic resonance imaging of the human spine and spinal cord at 3 Tesla. A technical note. Rivista di Neuroradiologia 18: 606-616, 2005.

Dr L. Albini Riccioli
Servizio di Neuroradiologia
Ospedale Bellaria
Bologna, Italy